CARE NED Work Package 3

Report on SMI Strand characterization

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Abstract

In the framework of the CARE-NED project, CERN placed a contract with ShapeMetal Innovation (SMI) in the Netherlands to develop a high performance Nb_3Sn strand and to fabricate the Nb_3Sn strand necessary for a 290 m long Rutherford-type cable made of 40 strands. The fabrication route used by SMI is the Powder-In-Tube (PIT) method. In this report, the characterization results of SMI strand are presented for both R&D and final strands.

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1. Introduction

In the framework of the CARE-NED project, CERN placed a contract with ShapeMetal Innovation (SMI) in the Netherlands to develop a high performance Nb_3Sn strand and to fabricate the Nb_3Sn strand necessary for a 290 m long Rutherford-type cable made of 40 strands. The fabrication route used by SMI is the Powder-In-Tube (PIT) method. Such a strand has to reach a critical current exceeding 818 A at 15 T and 4.2 K, corresponding to a critical current density in the non-copper part of around 1500 A/mm^2. This should represent a critical current larger than 1636 A at 12 T and 4.2 K, corresponding to a non-copper critical current of 3000 A/mm^2. In addition, the strand should include filaments of up to 50 µm in diameter, which constituted a genuine challenge before NED project.
In this report, the characterization results of SMI strand are presented for both R&D and final strands.

2. Research and Development phase

a. Strands B207 and B215: characterization results

SMI produced a ~ 300 m long strand, B207, at the end of 2005. This strand, with a diameter of 1.255 mm, included 288 filaments (~ 53 µm in diameter). However, its copper-to-non-copper ratio was found to be 0.96 instead of 1.25 as requested by the specification. Moreover, the critical currents were quite disappointing: 708 A at 15 T and 4.2 K (non-copper critical current density J_c ~ 1120 A/mm^2) and 1313 A at 12 T and 4.2 K (J_c ~ 2080 A/mm^2). The RRR of this strand was fully satisfactory (250).
SMI fabricated the B215 strand (950 m in one piece) in summer 2006, according to the B207 design. This strand, with a diameter of 1.257 mm, includes 288 filaments (with a diameter of ~ 50 µm) as well and has an adequate copper-to-non-copper ratio of 1.22. A cross section of the B215 strand, before heat treatment, is shown in Fig. 1.

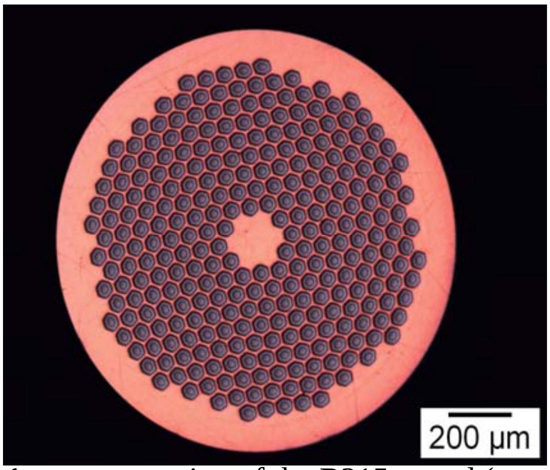

Figure 1: a cross-section of the B215 strand (not treated)

When reacted following the heat treatment schedule recommended by the firm (84 h @ 675 ^oC), the critical current of the B215 strand appeared to be quite promising. Indeed, measurements performed at the University of Geneva provided a critical current of 756 A at 15 T and 4.2 K, this value lying only 8 % below the minimal specified value and corresponding to J_c ~ 1350 A/mm^2. Critical current measurements done at CERN, INFN/Milano and University of Twente provided consistent results at lower magnetic fields, with a maximal value ever measured of 1397 A at 12 T and 4.2 K (J_c ~ 2500 A/mm^2) for the same standard heat treatment (SHT). One should mention that

the combination of such high current at 12 T and 4.2 K and fine filament size (~ 50 µm) constituted at that time a world record. The RRR values obtained were quite acceptable (70-80) although out of specification.
Magnetization measurements by means of a VSM instrument performed at Frascati showed only few flux jumps, thus indicating a fair stability of the B215 strand.

b. Heat treatment optimization studies on B215 strand

In order to try to increase both critical current and RRR values, heat treatment optimization studies were launched at CERN. The main purpose of the studies was to lower the reaction temperature in order to tentatively reduce the Nb_3Sn grain size, thus increasing the pinning center density and consequently the critical current. Seven heat treatment schedules were considered: 660 °C (84 h), 650 °C (84 h and 120 h) and 625 °C (200 h, 260 h, 320 h and 400 h).
For a heat treatment schedule of 320 h at 625 °C, the critical currents as measured on two B215 samples at Nijmegen for 15 T and 4.2 K are 823 A and 859 A, which correspond to a non-copper critical current density of ~ 1500 A/mm^2. Both values are within NED specification (I_c > 818 A) and they represent a critical current enhancement of ~ 9 % - 14 % as compared to SHT. At 12 T and 4.2 K, critical currents were consistently measured at both CERN and Nijmegen in the 1494 A - 1539 A range, corresponding to a current enhancement of up to 10 % and to J_c ~ 2700 A/mm^2.
In addition to these excellent transport current properties, it appears that the schedule of 320 h at 625 °C provides a very nice enhancement of the RRR values: ~ 220 for virgin strands and ~ 130 for strands extracted from a cable. Table 1 summarizes the main strand properties with both SHT and optimized heat treatment, together with the specified values. As shown by Table 1, the stringent NED specification is fully fulfilled thanks to the optimized heat treatment of 320 h at 625 °C.
Scanning Electron Microscope examinations and specific heat measurements, respectively performed at CERN and University of Geneva, undoubtedly indicated that a sample reacted with the optimized heat treatment has a Nb_3Sn phase with a higher quality (higher tin content, larger critical upper field and temperature and smaller grains), as compared to the sample reacted with the SHT.

HT	D [mm]	D_{eff} [µm]	Cu/non-Cu	Ic, 15 T [A]	RRR, virgin	RRR, extr.
675 °C/84 h	**1.258**	**49.8**	**1.22**	**756**	**70-80**	**30-60**
625 °C/320 h	**1.258**	**49.8**	**1.22**	**823-859**	**~ 220**	**~ 130**
Specification	**1.250 ± 0.004**	**< 50**	**1.25± 0.10**	**> 818**	**> 200**	**> 120**

Table 1: Main strand properties for standard (84 h/675 °C) and optimized (320 h/625 °C) schedules, together with specified values.

3. Final strand characterization

EAS/SMI was awarded the green light to launch the final strand production in fall 2007, according to the design of the strand B215. The final strand fabrication (12.7 km total length) is currently underway and should be completed by the end of 2008.

- A first strand, B228 (1 km long), was delivered to CERN in April 2008. This strand, 1.254 mm in diameter, has a copper-to-non-copper ratio of 1.19. When this strand is reacted during 120 h at 650 ^{o}C, its non-copper critical current density at 12 T and 4.2 K is between 2450 A/mm^2 and 2510 A/mm^2, i.e. very similar to that of B215. The RRR value of virgin strands is larger than 140 and is satisfactory as well.
- A second strand, B230 (~ 1.7 km long), arrived to CERN in July 2008. Its strand diameter is 1.253 mm and its Cu/non-Cu is 1.26. However, when reacted during 120 h at 650 ^{o}C, the strand exhibits critical current density values lower by 3 % - 4 % as compared to B215 and B228 strands, J_c being between 2400 A/mm^2 and 2430 A/mm^2. In addition, the RRR values are lower than for the former strands: between 50-90 as compared to values larger than 100 in the case of B215 and B228.
- A third strand, EAS 002 (3.8 km long) arrived to CERN in early November 2008. The strand diameter is 1.254 mm and its Cu/non-Cu is 1.22. When reacted at 650 ^{o}C during 120 h, critical current measurements indicated a satisfactory J_c value of ~ 2450 A/mm^2 in the non-copper part, ~ 2 % below the best results obtained for B215 and B228 strands.

4. Conclusions and perspectives

During its R&D phase for NED project, SMI successfully developed a strand, B215, with 50 µm filament and a non-copper part critical current density of J_c ~ 2500 A/mm^2, when reacted according to the firm heat treatment. Following, a heat treatment optimization performed at CERN, an enhancement of ~ 10 % was achieved by reacting during 320 h at 625 ^{o}C. With such a treatment, the strand fully fulfils the NED demanding specification.
EAS/SMI is currently achieving the production of the final strand. Three strands were already received at CERN. They were characterized with quite satisfactory results. EAS/SMI has completed the production of the final strand in January 2009 with the fabrication of the two remaining strand batches.